Staff Summary
Method 2B LCFS Application for the
Production of Cellulosic Ethanol from Sugarcane Straw
at the GranBio BioFlex Plant
Sao Miguel dos Campos, Alagoas State, Brazil

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Pathway Summary

This staff summary describes a prospective fuel pathway ("GranBio BioFlex Pathway") for cellulosic ethanol produced by GranBio ("GranBio") at the BioFlex plant under construction in the city of Sao Miguel dos Campos, Alagoas State, Brazil. The facility is expected to produce over 20 million gallons per year of ethanol using sugarcane straw and bagasse residues. The pathway described below, however, is based on the production of cellulosic ethanol using sugarcane straw obtained from sugarcane farms near the GranBio BioFlex plant as the only feedstock.

Sugarcane straw is comprised of the dried tops and leaves of the sugarcane plant. When the sugarcane crop is harvested mechanically, the tops and leaves are expelled by the harvesters and left on the farms. In partnership with the farmers, GranBio collects and bales the straw for subsequent transport to the BioFlex plant for conversion to ethanol. Some GHG impacts associated with soil nutrient makeup after straw removal have been assessed for the proposed pathway.

Once the sugarcane straw bales have been delivered to the BioFlex plant, the feedstock undergoes pre-treatment and hydrolysis for conversion of cellulose and hemi-cellulose components of the sugarcane straw to C_5 and C_6 sugars. This process is called enzymatic conversion and involves the use of specialty cellulase enzymes and some inorganic chemicals. The C_5 and C_6 sugars produced by pre-treatment and enzymatic conversion are then fermented into ethanol using yeast, just as in the sugarcane juice-to-ethanol pathway. The fermented beer is then distilled to produce near pure ethanol at the top of the column, and vinasse at the distillation bottoms.

The ethanol produced is loaded onto tanker trailers and transported to the Port of Maceio. At the port, the ethanol is loaded onto ocean tankers destined for California. Once the ethanol arrives in California, it is assumed to be transported by heavy-duty diesel tanker truck to a bulk terminal and subsequently to a fueling station.

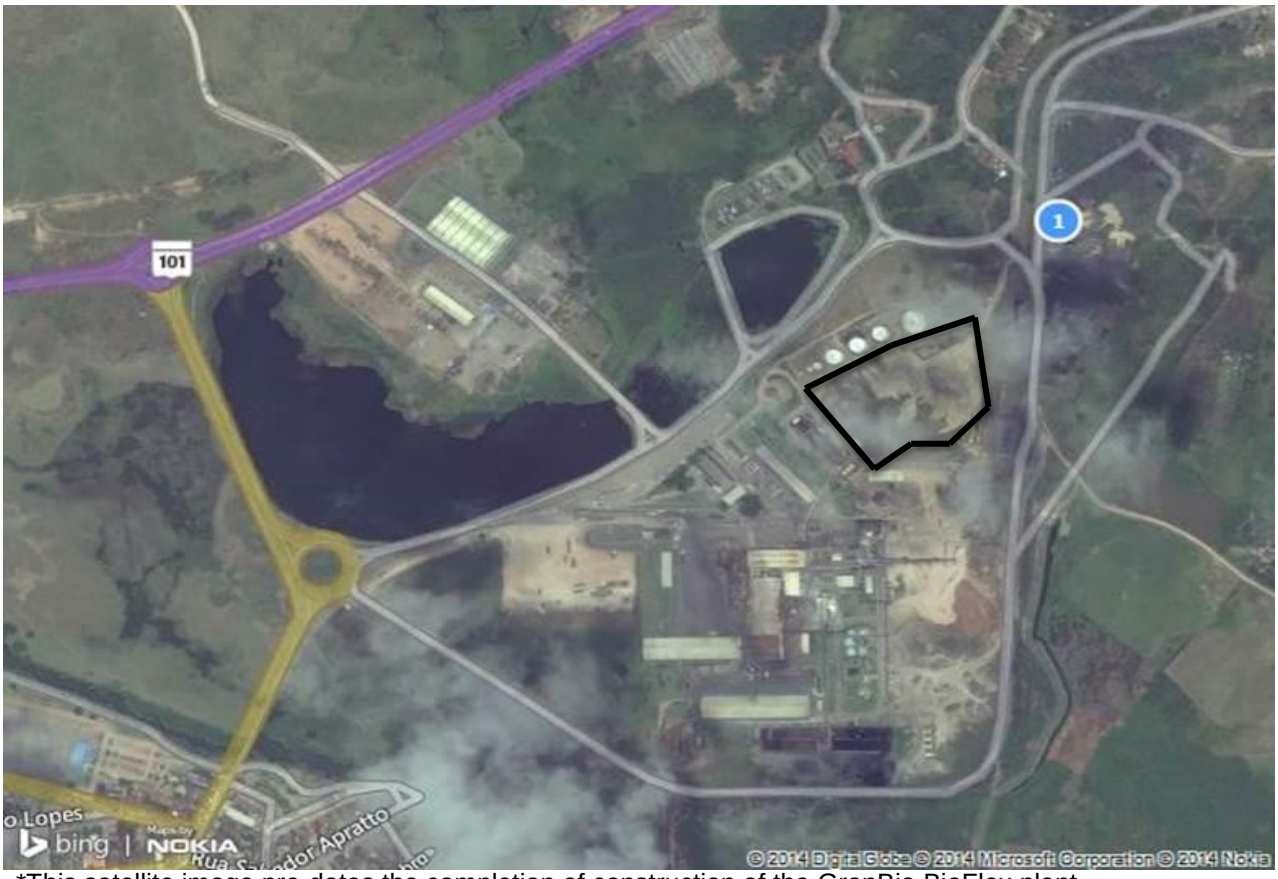
The biomass that remains after pre-treatment and hydrolysis consists of lignin, a primary component of the feedstock straw, along with the unconverted cellulose and hemi-cellulose biomass from the straw. The lignin is recovered, de-watered, and sent to the biomass boiler where it is consumed as process fuel. The steam produced by the

biomass boiler is used for process thermal energy as well as for the production of electricity using an extraction/condensing turbine. Staff has confirmed that more electricity is cogenerated by the lignin-fueled boilers than is necessary to meet the needs of the cellulosic ethanol production processes. The surplus energy is exported to the public grid, or used by other non-pathway-related processes at GranBio. In both cases, the surplus cogenerated electricity is considered to displace grid-based Brazilian marginal electricity and accrues a co-product credit in the proposed pathway. Only excess electricity produced from straw-generated lignin combustion is credited to this pathway.

Facility Location and Coordinates

The GranBio BioFlex cellulosic ethanol production facility is located in the city of Sao Miguel dos Campos within the State of Alagoas, Brazil. The geographic coordinates of the centroid of the BioFlex plant are 9°46'25" S (latitude), and 36°05'05" W (longitude). The newer BioFlex plant is constructed adjacent to the first-generation sugarcane juice-to-ethanol production facility shown in the satellite view below. The property line of the BioFlex plant is depicted with the black outline.

Satellite View of the GranBio BioFlex Plant*
Sao Miguel dos Campos, Alagoas State, Brazil



*This satellite image pre-dates the completion of construction of the GranBio BioFlex plant.

Carbon Intensity of the GranBio BioFlex Sugarcane Straw-to-Ethanol Pathway

The inputs GranBio used to calculate the Well-to-Wheels (WTW) carbon intensity (CI) of the GranBio BioFlex Pathway are described below.

Straw Collection and Transport

The straw used as a feedstock consists of the residue left on the ground by mechanized harvesting equipment. It is collected using windrowing machines, baled in the fields, and then stacked under cover. GranBio estimates an expenditure of approximately 140,000 Btus of diesel fuel energy per short ton of straw for the collection operation. GHG impacts from the straw cover use were also assessed. The cover is assumed to be made of reusable and recyclable plastic (HDPE) material with a 5-year life cycle. The baled straw is then loaded onto tractor trailers and transported to the BioFlex plant over a distance of 12 miles. The mode of transport was considered to be heavy heavy-duty diesel truck with a cargo payload of 33.5 tons.

Farming Chemicals

As stated previously, the sugarcane straw is considered to be a residue of the sugarcane cultivation and mechanized harvesting process. Agricultural phase GHG emissions do not accrue to residues. Removal of the straw from the ground however deprives the soil of essential nutrients, including the nitrogen (N), potassium (K), and phosphorus (P) present in the straw. GranBio expects to replenish some of this nutrient loss by returning vinasse bottoms and the boiler ash from the BioFlex plant to the sugarcane fields from which straw was collected. GranBio further assumes that all P and K nutrients displaced from the fields by straw removal are returned when boiler ash and vinasse are applied to the sugarcane fields. No additional P or K applications are required.

The GranBio BioFlex Pathway does require some amount of nitrogen for which synthetically produced nitrogen fertilizer application is necessary. The net amount of nitrogen fertilizer needed to replenish the soil is the difference between the straw nitrogen content and the amount of nitrogen in the vinasse bottoms and the boiler ash returned to the sugarcane fields, plus any loss of nitrogen fertilizer from application to the sugarcane fields. GranBio has determined this quantity to be 3,462 grams of nitrogen per short ton straw removed. The GHG impacts of makeup nitrogen fertilizer use due to sugarcane straw removal were estimated in CA-GREET.[1]

[1] Argonne National Laboratory and Life Cycle Associates LLC, 2009. California-Modified Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation Model (CA-GREET), Version 1.8b, Systems Assessment Section, Center for Transportation Research, ANL, December 2009.

The transport of boiler ash and vinasse bottoms to the sugarcane fields generates additional GHG emissions. Boiler ash and vinasse are transported an average distance of 12 miles by heavy-duty diesel truck from the plant to the fields. The trucks used for this purpose have a payload capacity of 23 short tons.

Process Chemicals and Specialty Enzymes

GranBio anticipates using chemicals such as sulfuric acid, potassium hydroxide, urea, as well as cellulase enzymes for pre-treatment and hydrolysis process operations. While their usage rates are considered to be confidential business information, the life cycle impacts of process chemicals and specialty enzyme use was determined using data available from the GREET1 (2013) Model.[2] In addition to chemical and specialty enzyme use, yeast is also used during the sugar-to-ethanol fermentation process.

The enzymes used at the GranBio BioFlex plant are transported from their production facility in Blair, Nebraska by heavy-duty diesel truck over 1,570 miles, and by ocean cargo ship for 4,335 miles. Since the cellulase enzymes are temperature sensitive, they must be transported in refrigerated containers ("reefers") for most of the journey. These reefers are assumed to be powered by diesel fueled-auxiliary power units (APU) that consume approximately 0.8 gallons of fuel per hour of operation. Fuel cycle emissions and tank-to-wheels GHG emissions from diesel fuel use in APUs were additionally estimated for the GranBio BioFlex Pathway. The process chemicals are transported only 34 miles from local sources, and therefore transport and distribution emissions are negligible. The yeast for the fermentation process is transported from the Netherlands using both heavy-duty diesel truck and ocean cargo transport. Yeast transport and distribution generates negligible GHG emissions.

Ethanol Production

Ethanol production generates GHG emissions when lignin is combusted, and when ethanol is produced and stored. Ethanol production and storage produces non-combustive VOC emissions. While lignin is a biogenic process fuel, CH_4 and N_2O emissions from combustion of lignin are not considered to be biogenic, and hence contribute to GHG impacts. GranBio expects improved emissions performance from its biomass boiler.

[2] Argonne National Laboratory, 2013. Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation Model (GREET Version 1), Systems Assessment Section, Center for Transportation Research, Argonne National Laboratories, October 2013.

Ethanol T&D

The ethanol produced is loaded onto tanker trailers and transported 37 miles to a bulk terminal at the Port of Maceio. At the port, the ethanol is loaded from the bulk terminal onto ocean tankers. The ethanol would be transported by ocean tanker over an average distance of 7,458 miles. Once the ethanol arrives in California, the mode of transport is assumed to be by heavy-duty diesel tanker truck with transport distances of 100 miles and 50 miles to a bulk terminal and a fueling station, respectively.

Co-Product Credit for Export of Surplus Cogenerated Electricity

The biomass boiler at the Steam, Power, and Electricity (SPE) unit at the BioFlex plant combusts lignin generated from the pre-treatment and hydrolysis of sugarcane straw biomass. For the sake of simplicity, GranBio has assumed that all steam generated from straw-based lignin combustion goes to the E/C turbine, and that the electricity as well as the thermal energy generated by the E/C turbine with generator feeds the cellulosic ethanol production process at the BioFlex Plant. GranBio has claimed that the cogeneration of electricity at the BioFlex plant from lignin combustion will produce 2.89 kilowatt-hours of surplus electricity per gallon of ethanol produced. This excess electricity would be exported to the public grid where it displaces Brazilian marginal electricity (net of 8.1 percent transmission and distribution losses). This displacement of Brazilian marginal electricity earns a co-product credit equal to the GHG emissions associated with the displaced Brazilian marginal electricity.

The aggregated inputs discussed above are summarized with the CI for the GranBio BioFlex Pathway in Table 1 below:

Table 1: Summary of Disaggregated WTW GHG Emissions for the GranBio BioFlex Pathway

Sugarcane Straw Residue-to-Ethanol Disaggregated Item	GHG Emissions: (g CO_2e/MJ)
Net Farming Inputs	3.91
Straw (Feedstock) Collection (T&D)	2.81
Straw (Feedstock) Transport to Mill	0.42
Cellulosic Chemicals and Enzymes	14.96
Ethanol Production	1.81
Ethanol Transport & Distribution	3.36
Addition of Denaturant	0.80
Well -to-Tank (WTT) Emissions	27.27
Less Surplus Electricity Cogeneration Export Credit	(21.09)
Total Well -to-Tank (WTT) Estimate	**6.98**
Carbon in Fuel (Tank-to-Wheels)	**-**
Indirect Land Use Change Estimates	0.00
Total Well -to-Wheels (WTW) Estimate	**6.98**

The proposed Lookup Table entry for the GranBio BioFlex Pathway is presented in Table 2 below:

Table 2: Proposed Lookup Table Entry for Fuel/Feedstock

Fuel	Pathway Identifier	Pathway Description	Carbon Intensity Values (gCO_2e/MJ)		
			Direct Emissions	Land Use or Other Indirect Effects	Total
Ethanol	ETHB001	2B Application:* Brazilian sugarcane straw residue-based cellulosic ethanol with electricity co-product credit.	6.98	0.00	6.98

* Specific Conditions Apply.

Applicable Operating Conditions

Operations at the Gran Bio BioFlex plant located in the city of Sao Miguel dos Campos in Alagoas State, Brazil will be subject to the following conditions designed to ensure that the CI of the sugarcane straw residue-based ethanol sold under the GranBio BioFlex Pathway described in this Staff Summary will remain at or below the value appearing in Table 2 above. The conditions must be met for every gallon of ethanol sold by GranBio in California. Exceptions are allowable only in the case of brief periods of planned maintenance or unpredictable, unavoidable, and uncontrollable *force majeure* events, or during initial startup to stabilize the ethanol and biomass energy production processes for a period not to exceed six months.

1. The applicant agrees to conduct emissions performance source tests of the Babcock & Wilcox VS-500/1 biomass boiler (rated at 200,000 kg/hour of supersaturated steam at 67 kgf/cm^{2}g and 520 degrees Celsius) constructed at the BioFlex plant. The source tests will be conducted at 70 percent of the rated steam output production capacity (140,000 kg/hour, 67 kgf/cm^{2}g, and 520 degrees Celsius), and at 90 percent of the rated steam output production capacity (180,000 kg/hour, 67 kgf/cm^{2}g, and 520 degrees Celsius). The results of the emissions performance source tests will be reported to the Executive Officer of the California Air Resources Board within six months of commercial startup and operation, or prior to export of ethanol produced at the BioFlex plant to California. Specific conditions governing the source test are as follows:

    a. The methane (CH_4) emissions rate from the main boiler stack or combustor shall be established as corresponding to the lignin fuel input rate to the boiler, as well as to the volumetric exhaust flow rate from the boiler,

    b. The CH_4 concentration in the main boiler or combustor exhaust shall be measured using U.S. EPA Reference Test Methods 1-4, and 25A (Determination of Total Gaseous Organic Concentration Using a Flame Ionization Analyzer),

    c. The nitrous oxide (N_2O) emissions rate from the main boiler stack or combustor shall be established as corresponding to the lignin fuel input rate to the boiler, as well as to the volumetric exhaust flow rate from the boiler,

    d. The N_2O concentration in the main boiler or combustor exhaust shall be measured using one of the following methods:

        i. EPA Method 320 at 40 CFR Part 63, Appendix A, Measurement of Vapor Phase Organic and Inorganic Emissions by Extractive Fourier Transform Infrared (FTIR) Spectroscopy,

ii. ASTM D6348-03 Standard Test Method for Determination of Gaseous Compounds by Extractive Direct Interface FTIR Spectroscopy, or

iii. An equivalent method, subject to California Air Resources Board Executive Officer approval.

2. The operating thermal efficiency of the Babcock & Wilcox VS-500/1 biomass boiler shall be verified at 70 percent of the rated steam output production capacity (140,000 kg/hour, 67 kgf/cm^{2}g, and 520 degrees Celsius), and at 90 percent of the rated steam output production capacity (180,000 kg/hour, 67 kgf/cm^{2}g, and 520 degrees Celsius). The operating thermal efficiency of the biomass boiler is defined as the ratio of the total enthalpy of the steam production output[3] to the total enthalpy of the feedstock used as input[4] fuel for the biomass boiler.

3. The source and efficiency performance tests specified in Applicable Operating Conditions 1-2 above shall be conducted by an independent, third-party emissions auditor certified to conduct emissions performance tests by a professional accreditation agency. The auditor shall submit a source testing protocol to the Executive Officer of the California Air Resources Board 30 days prior to the actual date of the source tests. A final report of the N_2O and CH_4 main boiler stack emissions performance source test results shall also be prepared and submitted to the California Air Resources Board Executive Officer.

4. Failure to comply with Applicable Operating Conditions 1-3 above will render the CI of the fuel specified in Table 2 invalid.

5. Following the submittal of the results of the biomass boiler emissions performance source tests and boiler efficiency tests, staff will determine whether the CI for the fuel can be verified at the proposed value specified in Table 2 above. If the source tests results indicate that the BioFlex plant is operating at a CI above that shown in Table 2, the Executive Officer will adjust the CI upwards.

6. GranBio will monitor and record the lignin and ethanol yields for every batch of sugarcane straw feedstock processed for ethanol and cogenerated power production. The records shall be averaged over 52 weeks and reported to the California Air Resources Board within 30 days after the end of the calendar year, GranBio fiscal year, or production year. Subsequent annual records shall be submitted using the same basis.

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[3] Total Enthalpy of the steam output produced (kJ/hr) = Mass Flow Rate of Steam (kg/hr) x Specific Enthalpy of the superheated steam (kJ/kg) measured at the output temperature and pressure.

[4] Total Enthalpy of the feedstock used as fuel (kJ/hr) = Mass Flow Rate of Fuel, dry basis (kg/hr) x Lower Heat Value (LHV) of fuel, dry basis (kJ/kg).

7. Sugarcane straw removal rates from farms around the GranBio facility in Sao Miguel dos Campos shall not exceed those specified in the GranBio application. The sugarcane straw removal rates shall also be contingent upon future research results identifying sustainable residue removal rates.

8. GranBio shall notify the California Air Resources Board if any of the following changes occur:

    a. Chemical or specialty enzyme usage in the pre-treatment and/or hydrolysis processes rise above the levels specified in the GranBio BioFlex Method 2B application, and

    b. The transport mode, or distance over which the chemicals or specialty enzymes transported changes. The Executive Officer may determine that any changes reported require a CI adjustment.

9. The CI for ethanol produced by the GranBio BioFlex Pathway using sugarcane straw residue as a feedstock includes a credit for electricity cogeneration and surplus exports. Only surplus electricity produced by the combustion of lignin generated from the sugarcane straw feedstock qualifies for the electricity co-generation and surplus export co-product credit.

    GranBio shall submit to the California Air Resources Board invoices of electricity sales to the public grid six months after startup of commercial production or stabilization of ethanol production. These invoices shall be accompanied by copies of the official ethanol production reports submitted to the government of Brazil (such as the "SAPCANA" reports[5]) for ethanol produced at the BioFlex plant. The invoices shall demonstrate a surplus cogenerated electricity export rate of no less than 2.89 kWh per gallon of ethanol produced. Official ethanol production reports shall continue to be submitted on a quarterly basis to the California Air Resources Board for a period of two years after startup of commercial production and stabilization.

10. Only steam and electricity from lignin combustion shall be utilized at the BioFlex plant. Furthermore, GranBio shall maintain boiler operations so that they meet the specifications provided in the Method 2B application.

[5] The SAPCANA Reports are the ethanol production and inventory report submitted by the producer to the Ministry of Agriculture, Government of Brazil.

Staff Analysis and Recommendations

Staff has reviewed GranBio's application for certification of a pathway for the production of ethanol from sugarcane straw residue and finds the following:

- Staff has replicated with reasonable accuracy the CA-GREETv1.8b and GREET1 (2013) carbon intensity calculations provided by the applicant. Staff has also verified with reasonable certainty the material and energy use information, and other input parameters used in the applicant's CI calculation.

- Staff recognizes that the plant energy (process heat and electricity) consumption values reported for GranBio's process reflect cogeneration activities from lignin combustion with surplus electricity export to the public grid. In addition, the pathway well-to-tank GHG emissions analysis reflects applicable credits for the return of boiler ash and vinasse waste products generated at the BioFlex plant to the sugarcane farms, and that the return of these wastes reduces the net fertilizer and nutrient makeup requirements from sugarcane straw removal in the field.

- On the basis of these findings, ARB staff recommends that GranBio's application for a Method 2B LCFS pathway be certified with a CI of 6.98 gCO_2e/MJ of ethanol fuel produced, subject to the operating conditions set forth in this document.